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ScienceDirect
Transportation Research Procedia 8 (2015) 80 – 88
Transportation Research Procedia
www.elsevier.com/locate/procedia

European Transport Conference 2014 – from Sept-29 to Oct-1, 2014

Valuing greenhouse gases emissions and uncertainty in transport cost benefit analysis

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Abstract

The transport sector has an important and increasing role in greenhouse gases emissions, and cost benefit analysis (CBA) of transport projects should give in this regard accurate and objective information. Indeed, many countries have included this concern in their CBA guidelines, but it typically consists simply in adopting an official value per ton of carbon emitted. Does this mean that the issue is correctly treated by CBA? Since "the devil is in the details" this paper reviews key items influencing the quality of CO2 emission valuation, estimating the order of magnitude of their effects and taking into account the nature and degree of imprecision and uncertainty associated with them.

Selection and peer-review under responsibility of Association for European Transport

Keywords: climate change; externality; emission valuation; uncertainty

1. Introduction

The transport sector has an important and increasing role in greenhouse gases (GHG) emissions: in France, it represents 34% of the national GHG emissions (13% in 1961), in OECD countries 27% (19% in 1961). Global climate change is a growing issue in the public debate, and cost benefit analysis (CBA) of transport projects should give in this regard accurate and objective information.

Indeed, many countries have included this concern in their CBA guidelines, but it typically consists simply in adopting an official value per ton of carbon emitted. Does this mean that the issue is correctly treated by CBA? Since

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Selection and peer-review under responsibility of Association for European Transport
doi:10.1016/j.trpro.2015.06.044

"the devil is in the details" this paper reviews key items influencing the quality of CO2 emission valuation, illustrating the order of magnitude of their effects and taking into account the nature and degree of imprecision and uncertainty associated with them. In CBA, valuation of CO2 effects is represented by the product of a unit value and a physical quantity. After presenting some insights on the first item of this product, the paper focuses on the second one and on the uncertainties associated with it.

In section 2, after a rapid review on the issue of fixing a unit value for CO2 emissions which is supposed to capture also the uncertainties associated with the effects of a marginal ton of CO2 emitted, we discuss the relevance of the usual international comparisons on CO2 values and propose an indicator more appropriate for transport CBA comparisons. Section 3 then discusses the quality of estimation of the variations in physical CO2 quantities emitted due to a given transport project, using feedback from ex-post studies. Section 4 presents the methods proposed in France for dealing with risks and uncertainties in CBA, with a focus on systemic risks, i.e. the risks associated with the links between the benefits of an investment and economic growth. Section 5 develops risk treatment methods for CO2 issues and gives illustrations for several types of emission reduction projects. Section 6 concludes the article.

2. Unit value of CO2 emissions and transport project CBA

There are several ways for approaching the issue of carbon value. The first consists in determining the carbon cost which optimizes the level of carbon emissions, by means of cost-benefit analysis. It is consistent with the usual procedure for monetising environmental effects such as air pollution or noise under a Pigouvian approach (damage cost). It nevertheless involves difficulties.

On the technical level, those difficulties were reflected in the discussions around the Stern report (2006), which adopted that approach. The other kind of difficulty raised by a cost-benefit procedure has to do with the international nature of the CO2 externality. From the national point of view of most countries, the benefits derived from self-imposed CO2 emission constraints are very limited and would justify only very limited constraints, international coordination and assessment are more adapted for such a global issue.

The cost-effectiveness procedure followed by the French authorities (Quinet A. in year 2008 completed by Quinet E. in year 2013), which is aimed at determining the shadow carbon price enabling France to meet its CO2 emission commitments, does not present the difficulties mentioned above. It should be noted, moreover, that the French commitments largely cover European agreements on the matter and are much more demanding than the agreements concluded at world level. France is faced with three sets of major commitments: the Kyoto Protocol, Europe's commitments to reduce greenhouse gas emissions unilaterally by 20% from 1990 levels by 2020, or even by 30% in the event of greater international effort on climate objectives; and the perspectives announced by the French Government in the Planning Act of 13 July 2005 "Establishing Energy Policy Guidelines" (confirmed by a new law project issued in July 2014), which supports the objective of reducing developed countries' emissions to a quarter of their existing level by 2050.

In Quinet (2008), several evolution paths were considered after 2030. In 2013 the Quinet Commission identified one specific path for public investment assessment: after 2030 the projection rule should follow the Hotelling principle (growth of the carbon value equal to the discount rate). So as to give a more precise idea on the evolution of CO2 values in France, the first unit value for CO2 emissions in transport CBA was introduced in 1995. It was then worth 74€2000 (constant value). This value was updated in 2004, rising at 100€2000 with an annual increase of 3% to be applied from 2010 on. The newest values still begin at 100€2000 for the year 2010.

Thus, when we consider only the values to be applied for present emissions, it seems that nothing has changed much in CO2 valuation during the past twenty years: indeed, the unit value just increased by one third, rising from 74 to 100 euros per ton of carbon (values for emissions in 2010). But when combined with the rules adopted for carbon value's evolution, for the discount rate and for the time horizon considered in transport CBA, it translates in fact into a sharp increase of CO2 valuation's weight in net present value (NPV) estimates. To illustrate this, we consider the net present value of sparing one ton of carbon (with certainty) each year over the time horizon considered in CBA. We see from table 1 that the corresponding value, according to the 1995 guidelines, would be a little less than one thousand euros. The 2005 guidelines, adopting an initial value increased by one third, but also a lower discount rate (4% instead of 8% previously) and a dynamic relative price rule, ends up in multiplying by 4 this value, around 4 000 euros. Extending the time horizon to 140 years instead of 50 years, as is proposed for the new French guidelines and still using the same relative price rule would lead to another sharp increase, around 10 000 euros. And adopting the full recommendations for the new guidelines would almost double this amount. As a whole, it means that the final value of sparing one ton of carbon each year over the time horizon considered in CBA has been multiplied by 20 between 1995 and the new guidelines.

Table 1: Net Present Value (NPV) of sparing one ton of CO2 every year over different time-horizons, estimated according to different assumptions on unitary values and evolution in time (derived from to assessment procedure of years 1995, 2004 and 2014)

		1995 procedure	2004 procedure	2014 procedure (Quinet E. Report)
CO2 unit values by time period		74 €2000/ton	100€2000 /ton, +3%/year from 2010 on	100€2000/ton +5,8%/year from 2010 to 2030, Hotelling-like from 2013 on
NPV of 1 ton carbon/each year	50 year time horizon	910 €	3 900 €	6 100 €
	140 year time horizon	920 €	9 800 €	17 600 €

The indicative «carbon weight test» above would be an interesting one to use for comparing national CBA methods, since it is more representative of the final weight of CO2 in CBA results than just comparing simply the present value adopted for CO2 in national guidelines, which is often misleading.

After these elements concerning the unit values for CO2 emissions, we will now focus on the physical quantities they are applied to in project CBA.

3. Quality of estimation of the physical CO2 quantities emitted

The core elements for estimating physical quantities of CO2 emitted are rather simple. The traffic model gives the variations of traffic levels expected due to the transport project, usually expressed in vehicle.km per type of vehicle, then an average unit emission per vehicle type is applied. Finally the variation in CO2 emissions induced by the project can be calculated by the product (we discuss only CO2 here, but in practice other GHG effects may be at stake, for instance for air travel with oxides of nitrogen and water vapor generated at high altitudes).

This simple process may present in practice many flaws. Ex-post studies often show for instance an overestimation of the CO2 variations, due to the assumption of constant unit emissions during the whole appraisal period. In reality, unit emissions are decreasing and we expect this to continue so as to reach the international objectives of climate change policies. Thus, unit emissions should be updated with the more recent observations, and their future evolution during the project's appraisal period should not be flat. For instance, CGDD (2011) indicates that, when assessed with an assumption of flat CO2 unit emissions sticking to observations made several years before the study was made, a set of high-speed line projects was estimated to spare 240 million-tons of CO2. But when using evolution assumptions more consistent with past observations, mid-term trends and impacts expected from climate change policies, this estimate was divided by two (110 million tons).

Convincing evidence is given by the national report on transport accounts for 2013 (CGDD 2014), which shows that unit CO2 emissions have continuously decreased from 1990 to 2012 for planes (from 180 g.CO2/passenger.km to 120 g.CO2/p.km) and for cars (from 200 g.CO2/vehicle.km to 160 g.CO2/v.km). The respective targets set for 2020 are 80 g.CO2/p.km and 120 g.CO2/v.km).The combination of observations of actual evolutions and the political objectives set for the future (2020 to 2050) clearly indicates that taking account of CO2 unit emission evolution paths is necessary for transport project CBA in order to avoid systematic estimation biases.

Traffic models become also progressively able to represent more accurately the traffic conditions on the networks (speed, congestion, ...), which allows to derive more precise CO2 emission estimates. But some important items are often forgotten in the final CO2 impacts of transport projects. Indeed, it is not only the traffic characteristics that change due to the project; maintenance and operation of the infrastructure and of the transport services do emit CO2 too, even if the order of magnitude of these emissions is usually much lower. Moreover, building the infrastructure and the vehicles needs much energy and generates important CO2 emissions. These issues are encountering an increasing interest for the improvement of infrastructures' technical design and their environmental assessment (Chester and Horvath 2009, Jullien et al 2014). In spite of recent research advice (Nocera et al., 2012 for instance), they still stay ignored from CBA studies to a large extent. However this does not mean that they are negligible compared to the traffic emissions. For new high speed lines, for instance, the emissions due to infrastructure construction may well represent 30% and more of the traffic emissions spared due to modal shift (CGDD 2011using RFF 2009 i.e. HSL Rhin Rhône case study). This ratio depends heavily on the level of usage of rail capacity. Chester and Horvath (2010) review GHG emissions for California high-speed rail and develop a more comprehensive life-cycle assessment. They estimate GHG payback. The time until return on investment, as seen from a GHG point of view, varies a lot depending on the occupancy ratios of the different modes: 6 years with high HSR occupancy, 70 years for 50% average HSR loading, and simply never for 25% loading. Such figures show that construction, maintenance and other usually neglected issues can easily represent several tenths of HSL traffic emission impacts, and even exceed them in case of low traffic. Looking at sources on ex-post project evaluations, we find the following orders of magnitude of overestimation or rail projects' traffic: Flyvbjerg et al (2005) conclude that passenger rail traffic was overestimated by 106% in average on their international sample (actual traffic was roughly 50% of estimated traffic), whereas in a more focused high speed rail analysis for France, Meunier (2012) obtains a lower overestimation ratio (24%). Other "induced emissions" are at stake, for instance the "well to tank" emissions generated for fuel production: depending on the tool used for estimating unit CO2 emissions, they will be taken into account (Tremove for instance) or not (Copert).

All these observations apply to the estimation of net variations of CO2 quantities emitted, comparing the situations with and without the project. Still, for CBA studies, another element should be considered: the level of internalisation of these CO2 costs. Indeed, if the costs of these additional emissions are reflected in the project's costs as they are estimated in the CBA study (which has rarely been the case up to now), this internalisation should be whether subtracted from the value of the corresponding emissions or properly considered symmetrically as a public revenue. In a world where all CO2 emissions would be perfectly priced, including all external effects, the value of CO2 emissions would be captured in the project's direct costs and indirect costs (e.g. user costs). In practice, the degree of internalisation will vary depending on the type of emissions. This will be directly impacted by the climate change policies and the specific measures chosen for reaching their objectives, as other important components of NPV may be (Meunier et al 2013), which calls for consistency checks between user costs, public revenues and external costs as defined and estimated by CBA. Other sources of uncertainty do exist, for instance the CO2 ratio of electricity production. In this case, the opening of energy markets may translate, for France, in an increase of this ratio, since the energy mix in France is presently much better in this regard than most other countries' (the value for 2011 is 61g.CO2/kWh compared to 536g.CO2/kWh world average – source IEA 2013).

Fig. 1 illustrates the outcomes of such corrections: index 100 corresponds to the initial estimate, successive (rounded) indexes correspond to the effect of CO2 quantity corrections, as indicated above, when all the overestimation causes reviewed above cumulate.

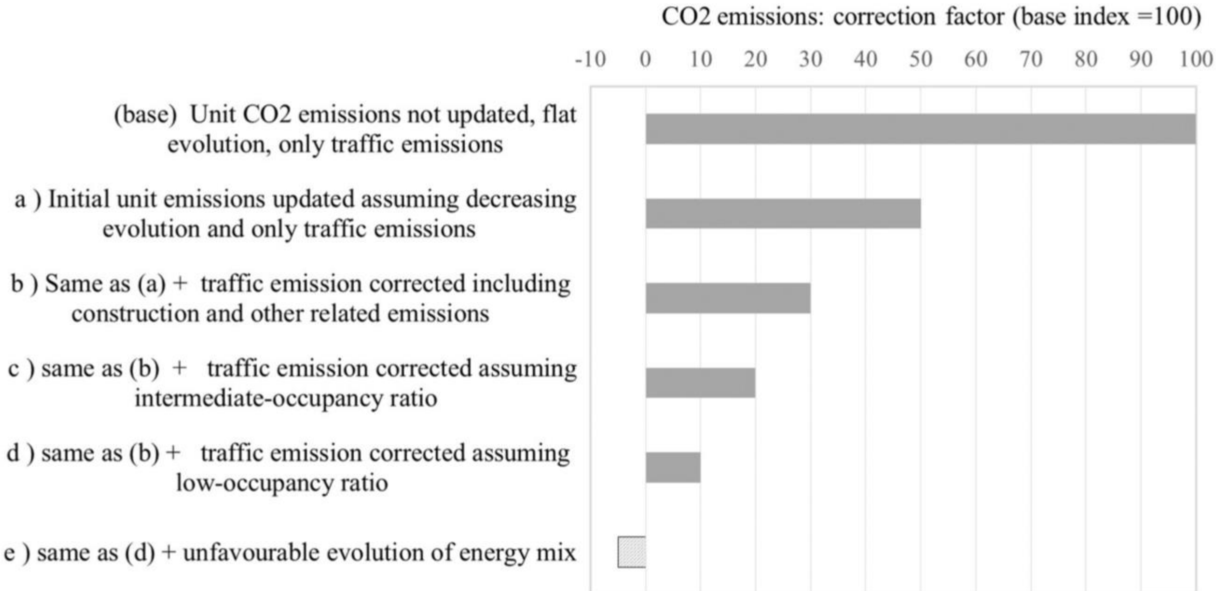


Fig. 1: Illustration of possible CO2 quantity corrections (e.g. CO2 spared by a rail project)

4. Dealing with risks and uncertainties in CBA

We will first present the general methods recently introduced in France for dealing with risks, then see how they could be applied to CO2 issues.

As regards the issue of risks in public investment projects for France, the Lebègue (2005) and Gollier (2011) reports made recommendations regarding analyses of risks specific to each project, as well as the understanding of systemic risks, the risks which correlate with overall economic development. Due to the law of large numbers, individual risks not correlated to economic development are compensated for across the entire set of projects and therefore the expected value of their monetized consequences (costs or advantages) is to be considered in CBA. This differs from systemic risks, whose effects are cumulative and for which we have to consider also a risk premium, positive or negative, correcting the expected value.

More precisely, systemic risks lead to a reduction in the value of the expected investment benefits if these benefits are positively correlated with economic activity, in which case they increase fluctuations, and vice versa if the correlation is negative, in which case they have a beneficial stabilizing effect. There are two ways to handle these effects technically: taking them into account directly in the net benefit flow (the "numerator" method) or by adjusting the discount rate depending on the level of risk (the "denominator" method).

In the latter approach, on which we will focus from now on, and under certain simplifying assumptions, the corresponding effect can be measured by the traditional product $\varphi\beta$, where φ is the macro-economic risk premium, a parameter common to all projects, and where β measures the correlation between project benefits and economic activity, a parameter specific to each project. Then a reduction in project benefits is easily expressed by an increase in the discount rate applied to them, which becomes, for each project, $r = r_f + \varphi\beta$, where r is the risk discount rate for the project, r_f the risk free rate, and $\varphi\beta$ the project's risk premium.

The Quinet (2013) report proposes a risk free rate of 2.5%, decreasing to 1.5% after 2070 and a risk premium of 2%, increasing to 3% after 2070. This choice is proposed in view of considerations that integrate lessons from the markets, macroeconomic considerations and long-term intergenerational concerns.

Applying this new approach for taking account of risks issues supposes, first, to determine the beta coefficient to be applied to changes in GHG emissions at the macro level. Very little is known about the value of that coefficient, for which several causalities may be involved, relating to the source of the uncertainties and to the direction of the causalities. A first causality puts the emphasis on the uncertainties relating to CO2 emissions and their consequences in terms of damage. According to this approach, a reduction in CO2 emissions has a positive impact on GDP, the correlation between the two is negative, and so, consequently, is the beta coefficient. But an inverse causality may be put forward, where the uncertainties essentially relate to GDP: a reduction in GDP leads to a reduction in emissions, the correlation between the two is positive, and so is the beta coefficient.

Which of these two causalities is preferable? There is not much evidence available. The tests performed by Gollier for the Quinet (2013) Commission, simulating the combined effect of the two uncertainties with probability ranges for each of them, speak in favor of a positive beta of 1 to 2. Those are the values which best reflect the correlation between trends in the social cost of carbon and GDP trends. Bearing in mind the opinions that exist in favor of a negative beta coefficient, a beta of 1 has been adopted. The meaning of this parameter must be clearly understood: it must be used when the aim is to discount a surplus variation resulting from a change in greenhouse gas emissions for a future year. The corresponding rate is given by $rf+1*\varphi = 0.025+1*0.02 = 4{,}5\%$.

It is hardly necessary to remind of the numerous uncertainties affecting these assumptions, whether technological (date of exhaustion of non-renewal energy resources, total volume of exploitable deposits, size of damages caused by emissions, possibilities of CO2 absorption, etc.) or political (national energy policies, international agreements, pricing of non-renewal energy resources, etc.). It must also be borne in mind that the justification for applying Hotelling's rule to determine the growth of the carbon price assumes a first-best economic situation, which is by no means the case. Normally the price of carbon, as well as its trend, should be derived from the long-term strategies and reference scenarios, which will include many other clauses and provisions than those resulting from a first-best situation (see for instance Rozenberg et al. 2013).

5. Dealing with uncertainties on CO2 quantities

In the case of an investment which has the effect of generating a saving of X_t tons of CO2 in future year t, how can we take account of the risks linked to X_t?

Many classical uncertainties have been listed above, which may introduce technical errors in the estimation of X_t but are not correlated with GDP and should only need to estimate an expected value for X_t. Most of these uncertainties may be treated by usual methods, such as correcting biases via more recent data on ratios (unit emissions) and more consistent evolution path assumptions, or enlarging CO2 impact analysis by using more comprehensive approaches like life cycle analysis. Sensitivity tests may help too, both for visualizing the range of variation of X_t and for making assumptions allowing to estimating an expected value. When possible, more likely for big projects and complex uncertainty issues, Monte Carlo methods may also be used, but keeping aware of their artificial precision. Indeed, such methods are very sensitive to the assumptions taken on the distributions, and on the correlations between variables, which most of the time are quite difficult to observe and to take into account.

With respect to systemic risks impacting X_t, a risk premium has to be considered, and hence in the beta method exposed above, to apply a coefficient β_x , translating the correlation between the avoided X_t quantities and GDP.

Since usually a large majority of CO2 effects come from traffic emissions generated or avoided, the systemic risks relate, in a first approach, to the link between GDP fluctuations and modal shifts or path choice shifts. Assuming that the elasticity of these shifts to the traffic levels is roughly 1, we end up considering the elasticity of traffic level to GDP. Elasticities vary a lot depending on the nature of traffic, usually growing from urban/ short distance trips to long distance and international trips.

Table 2: Elasticities of traffic to GDP adopted in Quinet (2013)

Urban passenger traffic	+0,4
Regional passenger traffic	+0,5
Long distance passenger traffic	+1,0

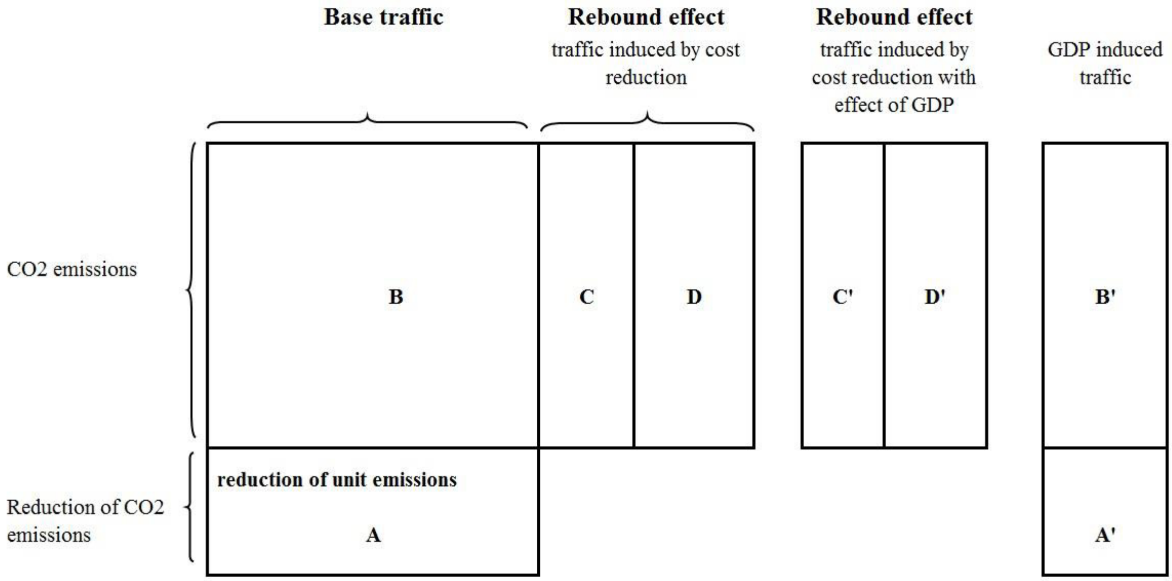
This gives a first idea on the values to be taken for β_x. In practice, since the GDP-elasticity of the value of carbon impact for year t: $VCO2_t$, is the sum of the GDP-elasticities of X_t and of the unit carbon value CV_t, the final beta is (β_x + 1) and the risk-adjusted discounted value for $VCO2_t$ for reference year 0 is equal to [$E(X_t)$ CV_t] divided by [(1+ 2,5%+ 2(β_x + 1)) t], remembering that CV_t evolves at a rate of 4,5% after 2030. Other impacts may be at stake such as a possible link between GDP fluctuations and unit emission of vehicles, which should then be added to the previous effect.

We will now give an illustration of some mechanisms that might be at work in relation to GDP evolution, for several kinds of projects or policy measures:

- reduction of unit emission of vehicles
- high speed rail line project
- motorway bypass project.

Let's take as a first example the case of a reduction of unit emission of vehicles obtained through a reduction of fuel consumption. Fig. 2 illustrates the measure's effects. When implemented it induces first a “mechanical” reduction A of transport emissions (if the traffic level is maintained) but also a reduction of transport costs for the users, generating, by a “rebound effect”, a traffic increase and related emissions (C+D). However, the cost of this consumption reduction measure has to be paid by someone, and it is likely to be at least partially internalized, perhaps in fixed costs, i.e. vehicle purchase cost. Thus, the rebound effect may be partially dampened (D), depending on the ratio “internalized added cost / fuel cost reduction” and on the way the measure's cost is internalized, i.e. related or not to the level of consumption. There may be also other types of impacts such as impacts on the choice of vehicle type when changing vehicles but we will not go any further here.

Now if a positive fluctuation occurs on GDP, what happens? There should be more “base traffic” and therefore more “mechanical reduction” A’, but also perhaps less sensitivity to costs, whether fuel consumption costs or added costs. The analysis becomes complex, the final outcome may depend on many details of actual implementation of measures. Therefore, it is not shocking to keep it simpler and to consider that the impact of the GDP increase on the reaction to unit fuel consumption reduction is roughly the unit consumption reduction multiplied by the GDP-induced increase in base traffic -estimated through the GDP-elasticity of traffic- corrected downwards by a “first step” rebound effect, i.e. by the additional fuel consumption induced by the fuel cost reduction -for the GDP-induced increase in base traffic, estimated using the elasticity of traffic to fuel costs.



	1) Base GDP	2) Changes due to GDP increase
Rebound effect due to reduction in unit fuel cost:	C + D	≈ (C + D) / B x B'
Reduction of rebound effect due to (partial) internalisation of measure	D	≈ D / B x B'
Effect of reduction of unit emission:	A - C	≈ A / B x B' - C / B x B'

Fig. 2: Illustration of possible effects of a positive GDP variation / case reduction of unit fuel consumption

The following examples give an indicative order of magnitude of the rebound effects. A measure allowing a reduction of unit fuel consumption of 10%, without internalization of the measure's cost, would end up with a final reduction of about 7% of CO2 emissions due to the rebound effect, using a price-elasticity of -0,3 for fuel consumption, based on short-term price elasticities commonly estimated (Graham and Glaister, 2002). An increase of 1% of GDP would generate 0,5% additional traffic, using an elasticity of +0,5 (see Table 2, for regional traffic) and the final emission spared by the measure would increase by 0,35%, taking into account the rebound effect. The emissions spared would be more important in case measures costs were (fully or partially) internalized in fuel costs, due to the reduced rebound effect.

Let us now consider a High-speed Rail line project. The main mechanisms at work for CO2 impacts are the modal shift made possible by the project, from road traffic and air traffic, and the induced traffic which may at least generate additional road trips at the ends of multimodal trips. Now if a positive fluctuation occurs on GDP, there should be more "base traffic" but what about modal shift and induced traffic? If the relative attractiveness of high-speed Rail (HSR) stays unchanged, modal shift should stay roughly proportional to the base traffic, i.e. should increase. The HSR is also likely to be a little more attractive for road users because it spares time and there is evidence of a positive GDP-elasticity of the value of time. But it might go in the opposite direction for plane users. This means that representation and knowledge on induced traffic and on modal competition are important here.

Other possible phenomena could be explored such as the possibility of a strictly positive elasticity of unit vehicle fuel consumption to GDP (in the present case it would increase the CO2 gains due to the project) or a reduced sensitivity to costs, whether fuel consumption costs or added costs, changing thus the competition conditions between the modes. Once again the analysis becomes complex, the final outcome may depend on several mechanisms which impacts' orders of magnitude are not straightforward to estimate. Simulations using multimodal traffic models are needed for deriving the reaction of the CO2 component of NPV due to a fluctuation in GDP, and for deriving a beta value for X_t in this case. If we assume that the first mechanism gives a good approximation of the final outcome, since we have seen that long distance passenger traffic had a beta of 1, β_x would be close to 1 too, possibly lower due to the road trip generating effect of induced traffic.

We will end these illustrative cases by a project of motorway bypass allowing reduced congestion in the agglomeration and finally gains in CO2 emissions: the analysis is similar to the HSR case i.e. a positive GDP fluctuation is likely to give an increased shift from congested roads to the motorway, with possible concerns about induced traffic and positive elasticity of unit vehicle fuel consumption to GDP. The first of these two items would be expected to reduce a little the CO2 gains whereas the second would be expected to increase them somewhat.

We have seen diverse and potentially complex and interrelated mechanisms through which GDP fluctuations may impact the net CO2 impacts of projects or policy measures. This highlights, among other things, the importance of developing knowledge on elasticities and induced traffic. In practice, risk analyses need a good level of technical compatibility and consistency between CBA assumptions and methods on the one hand, and traffic models assumptions and internal logic / algorithms on the other hand.

In this paper we have focused on CO2 issues, but the methods for taking account of risks for CO2 issues are applicable and, as we have seen above, closely linked to risks impacting traffic outcomes, and usually the CO2 component in net present value (NPV) weights just a few percent: the new CBA rules adopted in France for CO2 may increase this share but for the vast majority of projects, other issues and especially time gains should keep a predominant share of NPV. This means also that, for transport project CBA, taking account of risks for traffic issues will quite generally have stronger consequences on NPV than the impacts on the CO2 component of NPV.

6. Conclusions

We have presented here the new methodologies proposed in France for CO2 valuation in CBA and for coping with risks and uncertainties. Comparing national CO2 unit values should be made cautiously and rather than comparing present face values of CO2, more CBA fitted indicators would be highly preferable as the ones proposed at the end of section 2.

Analysing the uncertainties bearing on the estimation of a project's impact on CO2 quantitative emissions led us to explore several dimensions and to reach the following conclusions:

- the uncertainty on CO2 physical quantities deserves attention since errors in this regard are not negligible and may impact not a few percent but the order of magnitude of the quantities estimated
- non systemic uncertainties may be treated with usual tools (bias corrections, use of more recent information and accurate projections, sensitivity tests) and only need an informed and accurate estimate of expected values
- MonteCarlo methods are an attractive tool but one should stay aware that they do not replace knowledge improvements and may amplify the consequences of insufficient knowledge by giving seemingly precise but potentially misleading results (for instance if correlations between key variables are not been properly taken care of)
- systemic risks are more complex to deal with, they suppose to add a risk premium (theoretically positive or negative) to the expected impact; they need in depth analysis of the diverse and interrelated mechanisms at work, especially as regards modal shifts and induced traffic and their relation to GDP; they suppose also enough compatibility and consistency between CBA assumptions/methods and traffic models/emission models;
- a simple way of dealing with the risk premium of systemic risks is to use the beta method, but knowledge on correlations and beta values should be examined further for different types of projects (and the intra-type variations may be high, too)
- the methods for taking account of risks for CO2 issues are applicable, and closely linked, to risks impacting traffic outcomes; for transport project CBA these traffic impacts will quite generally have stronger consequences on NPV than the impacts on the CO2 component of NPV.

We may hope that future research and ex-post studies will help to understand better CO2 emission uncertainties and their mechanisms. This is a recent field in transport CBA but knowledge on now common issues such as time gains, safety, etc., had also to be built in the early times they appeared on the public agenda and on CBA's agenda.

References

CGDD, 2011. Evaluation globale du projet de Schéma national des infrastructures de transport. Commissariat Général au Développement Durable, Paris.

CGDD, 2014. Les comptes des transports en 2013, collection Références.

Chester, M. V., Horvath, A., 2009. Environmental assessment of passenger transportation should include infrastructure and supply chains..Environmental Research Letters 4(2), 024008.

Chester, M., Horvath, A., 2010. Life-cycle assessment of high-speed rail: the case of California. Environmental Research Letters 5(1), 014003.

Flyvbjerg, B., Holm, M.K.S., Buhl, S.L., 2005. How (in)accurate are demand forecasts in public works projects? The case of transportation, Journal of the American Planning Association 71/2, 131-146.

Gollier, C., 2011. Calcul du risque dans les investissements publics, rapport du Centre d'analyse stratégique, la Documentation française, Paris.

Graham, D. J., Glaister, S., 2002. The Demand for Automobile Fuel: A Survey of Elasticities. Journal of Transport Economics and Policy 36/1, 1-25

Jullien, A., Dauvergne, M., Cerezo, V., 2014. Environmental assessment of road construction and maintenance policies using LCA. Transportation Research part D 29, 56-65.

IEA, 2013. CO2 emissions for fuel combustion Highlights, International Energy Agency report, october 2013.

Lebègue, D., 2005. Le prix du temps et la décision publique, Commissariat général du Plan.

Meunier, D., 2012. Integrating risks in project assessment: methodological and empirical feedback from ex-post studies. Kuhmo Nectar Conference, Berlin.

Meunier, D., Quinet, E., Quinet, A., 2013. Project appraisal and long term strategic vision. European Transport Conference 2013, Frankfurt, Germany.

Nocera,, S., Maino, F., Cavallaro, F., 2012. A heuristic method for determining CO2 efficiency in transportation planning. European Transport Research Review 4/2, 91-106.

Quinet ,A., 2008. La valeur tutélaire du carbone, rapport du Centre d'analyse stratégique, La Documentation Française, Paris.

Quinet, E., 2013. L'évaluation socio-économique des investissements publics, rapport du Commissariat Général à la Stratégie et à la Prospective, La Documentation Française, Paris.

RFF, 2009. Premier Bilan carbone ferroviaire global – la ligne à grande vitesse Rhin-Rhône.

Rozenberg, J., Vogt-Schilb, A., Hallegatte, S., 2013. How Capital-Based Instruments Facilitate the Transition Toward a Low-Carbon Economy, The World Bank Policy Research Working Paper.

Stern, N., 2006. The Economics of Climate Change: The Stern Review. HM Treasury, London.